

Human Factors Evaluation of Conflict Detection Tool for Terminal Area

Terminal-area Tactical Separation-Assured Flight Environment (T-TSAFE)

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Abstract—A conflict detection and resolution tool, Terminal-area Tactical Separation-Assured Flight Environment (T-TSAFE), is being developed to improve the timeliness and accuracy of alerts and reduce the false alert rate observed with the currently deployed technology. The legacy system in use today, Conflict Alert, relies primarily on a dead reckoning algorithm, whereas T-TSAFE uses intent information to augment dead reckoning. In previous experiments, T-TSAFE was found to reduce the rate of false alerts and increase time between the alert to the controller and a loss of separation over the legacy system. In the present study, T-TSAFE was tested under two meteorological conditions, 1) all aircraft operated under instrument flight regimen, and 2) some aircraft operated under mixed operating conditions. The tool was used to visually alert controllers to predicted Losses of separation throughout the terminal airspace, and show compression errors, on final approach. The performance of T-TSAFE on final approach was compared with Automated Terminal Proximity Alert (ATPA), a tool recently deployed by the FAA. Results show that controllers did not report differences in workload or situational awareness between the T-TSAFE and ATPA cones but did prefer T-TSAFE features over ATPA functionality. T-TSAFE will provide one tool that shows alerts in the data blocks and compression errors via cones on the final approach, implementing all tactical conflict detection and alerting via one tool in TRACON airspace.

Keywords- Conflict Detection, CD&R, Terminal area

I. INTRODUCTION

Managing terminal area traffic is challenging due to the density of traffic and complexity of trajectories and separation standards. Conflict Alert is a short time-horizon conflict detection tool currently in operational use in both the en route and terminal area in the U.S. National Airspace, but it is often inhibited or desensitized in the terminal area because it generates a high number of false alerts. Similarly, The Short Term Conflict Alert (STCA) in the Belgian Military airspace, Semmerzake (see Appendix D. of [1]) has rendered STCA ineffective due to high number of nuisance alerts. These tools help maintain safety in the current system, sometimes at the

expense of capacity, because controller workload is often considered as a limitation to capacity [2].

Conflict Alert uses only dead reckoning to determine when aircraft are in dangerous proximity to each other as compared to alerting for losses of separation. Tang et al. [3] augmented the legacy dead reckoning approach with flight trajectory intent information to create a short time-horizon tool called Terminal-area Tactical Separation Assured Flight Environment (T-TSAFE). The tool was developed to address the inadequacies of Conflict Alert (CA), which is used in the current air traffic control milieu. A comparison of T-TSAFE against a model of Conflict Alert, in a fast-time environment, found that T-TSAFE reduced the false alert rate from 20 per hour to 2 per hour when altitude intent was available and provided an average alert lead-time of 38 seconds [3].

There are several conflict detection tools in the current National Airspace such as Conflict Alert (CA), Minimum Safe Altitude Warning (MSAW) system and Automated Terminal Proximity Alert (ATPA) in the final approach that do not communicate with each other. It would be ideal to have a single tool throughout the terminal airspace including the final approach. This research aims to test the T-TSAFE algorithm for depicting alerts in the data block and providing for a visual graphic for showing compression errors in the final approach.

The objective of the current work was to test the T-TSAFE algorithm driving the visual graphic similar to ATPA in the final approach phase, and also vary the presence or absence of aircraft in the traffic flying under visual flight rules. ATPA shows the final approach controller a visual graphic (cones) for separating two aircraft flying straight in on final, and provides warnings when separation is predicted to be lost.

The paper describes previous research in the field followed by a section that compared the T-TSAFE cones with the ATPA cones. It continues to delineate the experimental conditions and the relevant results are followed by discussion and conclusions.

II. BACKGROUND

The Federal Aviation Administration (FAA) has forecasted an increase in air traffic demand that may see traffic more than double by the year 2025 [4] [5]. Increases in air traffic will burden the air traffic management system, and higher levels of efficiency will be required. Maintaining current levels of safety will be more difficult in a more constrained and crowded terminal airspace. Thus, automation is proposed to aid the terminal area controllers with the task of assuring separation.

Terminal airspace has proven to be difficult for tactical conflict detection automation. The factors that contribute to this difficulty include dense traffic, frequent large turns made by aircraft, imprecise flight plans, a complex set of separation standards and the fact that the aircraft operate close to the minimum separation standards leading to compression errors (horizontal separation violation) on approaches [3]. In the current-day environment, CA, a legacy system, was shown to be inaccurate at times, and have a high rate of false alerts [6]. An analysis of Conflict Alert showed that in the terminal area, controllers respond to alerts 56% of the time [7], which suggests a high false or high nuisance alert rate.

Eurocontrol has been developing guidelines for a Short Term Conflict Alert (STCA) [1]. The guidelines define environment data and parameters that should be used for conflict detection such as type of flight, wake category, Reduced Vertical Separation Minima (RVSM) status, cleared or block flight levels, and manually entered flight levels. The STCA guidelines propose using the linear prediction filter (dead reckoning) with a look-ahead time along with cleared flight levels entered by the controller, when available.

The new algorithm for tactical conflict detection (T-TSAFE) developed by Tang et al. [3] aims to address the inadequacies of Conflict Alert in terminal airspace and incorporates some of the recommendations made by Friedman-Berg et al. [9], e.g., using a single analytic trajectory that takes into account both flight intent information and the current state of the aircraft. It also follows several of the Eurocontrol's STCA guidelines such as taking into consideration different route structures, using flight intent information from the airspace definitions, speed restrictions and Area Navigation (RNAV) departure routes, segments of nominal TRACON routes and manually entered altitude clearances by controllers.

Tang et al. [3] compared the T-TSAFE algorithm with a model of the Conflict Alert algorithm using recorded data from Dallas/Fort Worth TRACON that included 70 operational errors between January 2007 and April 2009. An analysis of fast-time simulation data showed that T-TSAFE would have prevented most of these operational errors, and that T-TSAFE also yielded a false alert rate of 2 per hour with 38 seconds of lead alert time, giving the controller more time to address conflict situations before they became critical. This finding addresses another Eurocontrol STCA guideline, which is to provide an alert with ample time to conflict so that the controller has enough time to de-conflict the two aircraft. In addition, when the algorithm has information about where and which aircraft will level off, fast time analyses showed further significant reductions in false alerts. The potential benefit from additional altitude intent information was the rationale for

asking controllers to enter some commanded altitudes in the current investigation. This is similar to Eurocontrol's guidelines for Cleared Flight Levels (CFL) for the STCA [1], where controllers are expected to enter the assigned altitudes manually.

Subsequent to T-TSAFE's fast-time study [3], several HITL studies also tested T-TSAFE in the terminal airspace [8][9]. Results provide additional evidence for T-TSAFE's efficacy, and the possible usefulness of altitude entries made by the controller. The initial HITL study [9] examined controllers' usage of the ATPA cones, which were used to automatically depict minimum separation between the aircraft on final approach, and the next HITL study [8] compared cones driven by the ATPA algorithm to T-TSAFE alerts in the data block (Fig. 1). Either the ATPA cones were shown to provide warnings or the T-TSAFE alerts were shown in the data block of the aircraft on final approach. The Federal Aviation Administration (FAA) recently fielded ATPA during the final approach phase of flight [10]. The tool provides controllers with visual warnings if the minimum separation criteria is being exceeded or has the potential for being exceeded. The controllers give commands to pilots to make necessary maneuvers. ATPA may also allow the controllers to achieve better arrival rates by maintaining precise separation between aircraft. The tool shows the controller a cone, whose narrow end is placed on the aircraft icon and its length is based on the required separation between the two aircraft flying in-line (Fig. 3).

Currently there are several conflict detection tools in the terminal area such as CA, MSAW, ATPA and each of these tools acts independently. Allendoerfer & Friedman-Berg (2012) discuss that these tools are not integrated, so they do not exchange inputs or outputs, and sometimes provide contradictory information to the user [11]. They also found that tools developed in a non-integrative manner interfere with each other and require additional effort for controllers to manage the system. T-TSAFE was extended to include cones on final approach to integrate some of these tools. T-TSAFE attempts to improve upon, and bridge any gaps or missing functions in CA and ATPA.

III. EXPERIMENTAL TOOL-T-TSAFE

The current investigation examined using the T-TSAFE algorithm to drive ATPA-like cones and compared them with the original implementation of the ATPA cones. The objective of the study was to examine final approach operations using either ATPA cones or T-TSAFE cones under different operating conditions.

The main tool used in the experiment was T-TSAFE. The alerts were shown in the data block and also as cones. There were different levels of alerts and they are all described in this section. T-TSAFE uses 1000 feet minimum vertical separation, wake turbulence lateral separation standards, and a look-ahead time of 120 sec to calculate conflicting trajectories. T-TSAFE alerts the controllers to a conflict by placing the number of seconds to predicted Loss of Separation (LoS) at the end of the first line in the data block, and the call sign of the conflicting

aircraft in the third line of the data block, both in yellow or red (Fig. 1). There are two levels of alerts annunciated in the data block- yellow alerts when the time to predicted loss of separation is greater than 45 sec, and red alerts when the time to LoS is below 45 sec. If more than one other aircraft is involved in a conflict, the third line shows the call sign of the aircraft closest to a LoS. The controller can also roll the cursor over any aircraft showing a conflict, causing the data blocks of all other conflicting aircraft on the display to turn yellow for five seconds.

UAL411 50	UAL411 35
120 160	120 160
DAL329	DAL329

Figure 1. T-TSAFE Data Tag (yellow and red alerts)

The controllers also entered assigned altitude to the system and were provided resolution advisories that were either altitude or speed advisories. Both Speed and Altitude resolution advisories are shown in magenta color to the controller, in the second line of the data block. The assigned altitude entered by the controllers via keyboard is shown in green color in Fig. 2. The controllers were not required to make any entries for speed commands they issued to the controllers. As soon as the T-TSAFE algorithm receives altitude intent from the controller's input, it no longer detects the conflict and removes it from the data block, thus decreasing false alerts. The green assigned altitude stays until the aircraft ascends or descends 300 ft above or below the assigned altitude.

AAL280 60
200 A250 A220
SWA192

Figure 2. T-TSAFE Altitude Resolution and Altitude Entries

The current research compared ATPA cones (Fig. 3) with T-TSAFE cones (Fig. 4) in the final approach area. The T-TSAFE cones have the same visual graphic as the ATPA cones, but they also have added time to LoS in the data block. Other differences between the ATPA and T-TSAFE cones are described in Table I.

As mentioned in Table I, ATPA cones appear on the aircraft only after the aircraft are established on the localizer, and the cones provide alerts in the form of yellow and orange cones for compression errors only. The warning yellow and orange ATPA cones did not also display T-TSAFE alerts to avoid confusion and clutter. This phase required controllers to enter the level-off altitudes (issued to the pilots as verbal commands) via keyboard command for the purpose of reducing the number of false alerts. These altitude entries had no effect on the ATPA cones.

TABLE I. DIFFERENCES BETWEEN ATPA & T-TSAFE CONES

ATPA Cones	T-TSAFE cones
Cones show compression error	Cones show Loss of Separation (LoS)
Cones appear after established on localizer	Cones appear 30 sec before being established on localizer
Altitude Intent has no impact	Altitude intent reduces false alerts
Yellow warning cones when predicted time to LoS is 45 sec	Yellow warning cones when predicted time to LoS is greater than 45 sec
Orange warning cones when predicted time to LoS is 24 sec	Red warning cones when predicted time to LoS is less than 45 sec
T-TSAFE compression alerts are suppressed on aircraft with ATPA cones	Only time to LoS is shown in data block on aircraft with T-TSAFE cones
Conflict predictions between aircraft are made with the aircraft physically ahead	Conflict predictions between aircraft are based on the schedule to the runway ahead

The T-TSAFE cones evaluate required separation, thus sufficient altitude separation prevents the T-TSAFE cones from showing yellow or red alert status. ATPA cones, on the other hand, turn yellow or orange if there is a compression error despite sufficient altitude separation between two aircraft. The cones for T-TSAFE appear 30 sec before aircraft are established on the localizer. T-TSAFE builds predictions based on scheduled arrival at the runway, allowing for the accurate display of compression alerts even when two aircraft are not yet physically in line. ATPA cones are built for the trailing aircraft only when it is physically behind another aircraft. At face value, the ATPA and T-TSAFE cones appear the same with the exception of additional time-to-LoS shown in the data tag for the T-TSAFE cones for compression errors (Fig. 3 & Fig. 4). The color of the T-TSAFE warning cones matches the color of the T-TSAFE alerts in the data block (Fig. 3).

Other similarities between the ATPA cones and T-TSAFE cones include: The blue cone shows no LoS or compression error; the number displayed inside the cone is the distance between the leading aircraft and current aircraft; the size of the cone for both ATPA and T-TSAFE is based on wake requirements given the aircraft types for both the aircraft. The experiment examined T-TSAFE cones with ATPA cones under IFR and Mixed operating conditions. The Mixed operating conditions involved having part of the traffic on visual approach.



Figure 3. Automated Terminal Proximity Alert

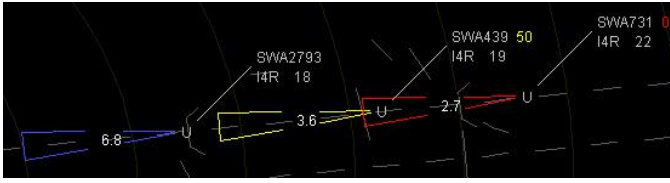


Figure 4. T-TSAFE cones (Time to LOS shown in data tag)

The final approach controller made keyboard entries for aircraft that were put under visual approach to runway 24R in the Mixed operating conditions. They pushed the keys “4R” on the keyboard to assign the aircraft to a visual approach on 24R. The scratch pad entries in the data block can distinguish between an aircraft on ILS approach and visual approach. The aircraft on ILS approach to 24R shows “14R” and to 25L shows “15L”. The aircraft on visual approach to 24R shows “24R” (Fig. 5) and to 25L shows “25L” in the scratch pad of the data block.

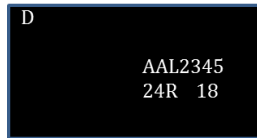


Figure 5. Data tag showing visual entry to 24R

Another new tool explored in the study was controller look-ahead time. The controllers were provided a tool that allowed them to set the look-ahead time on the display to control the alerts they wanted to see on their scopes. They were allowed to select from a drop-down menu – 45, 60, 90 or 120 sec as their look-ahead time. For example, a controller could select 60 sec as the look-ahead time, and all alerts within the 60 sec of predicted time to conflict were shown on the display. This allowed controllers to control how early and how many conflicts they chose to see on their scope.

IV. METHODOLOGY

The experimental approach was a Human-In-The-Loop (HITL) evaluation of the T-TSAFE tools under current-day operational conditions.

A. Experiment Matrix.

This study phase tested four conditions: T-TSAFE cones under Instrument Flight Rules (IFR) and Mixed operating conditions, and ATPA Cones under IFR and Mixed operating conditions. Four traffic scenarios were exercised with each of the conditions for a total of 16 runs. The two variables being manipulated are cone type-T-TSAFE and ATPA, and operations type- IFR and Mixed.

B. Traffic Scenarios

The study simulated five arrival streams to and one departure stream from Los Angeles International Airport (LAX) using current airspace and procedures within the TRACON. The scenarios were designed to create situations that would result in a LoS between aircraft unless a controller intervened. Occasionally, the controllers were able to successfully avoid conflicts for extended periods due to early interventions. It was therefore necessary to add conflicts to the

scenarios using observers collaborating with pseudo pilots. Each scenario involved heavy current-day traffic, with all LAX traffic under Instrument Landing System (ILS) simultaneous approaches on runways 24R and 25L for Conditions A and B. In the Mixed conditions (Condition C and D), some aircraft approaching runway 24R managed by the Stadium controller operated under visual flight rules, while the rest of the traffic to runway 24R and all approaches to runway 25L operated under Instrument Flight Rules (IFR).

C. Experiment Procedures

The study was conducted over a two-week period with two teams of controllers, each participating for a week. Eight recently retired controllers served as participants, each controlling simulated traffic in the Southern California Terminal Radar Approach Control (TRACON) for approximately eight hours total. Each controller team consisted of four controllers that had retired less than two years ago from Southern California TRACON. Both controller teams were briefed on the T-TSAFE concept, the T-TSAFE interface, and the conditions of the study. During each week, the controller team completed 16 runs, four runs in each of the four different conditions, rotating through four different traffic scenarios. Controllers also rotated between sector positions after each run. Pseudo-pilots flew all the aircraft in the scenarios. The controllers worked the East Feeder and Zuma, feeder sectors, and Downe and Stadium, approach sectors in the Southern California TRACON, rotating positions after each run. All controllers completed questionnaires after every run and took part in a debrief session at the end of the study. Both conflict detection performance and controller subjective feedback were collected and analyzed, to characterize the performance of the T-TSAFE prototype.

V. RESULTS & DISCUSSION

Both the digital and questionnaire data were collected and analyzed for the two independent variables: Operating conditions (IFR and Mixed), and Cone types (ATPA and T-TSAFE). Only the Stadium controller experienced the Mixed condition, therefore, the analysis of the Mixed condition pertains to the Stadium controller only. This is compared with the IFR condition analysis pertaining to all four controller positions. Also, the cones were displayed to only the final approach positions-Stadium and Downe, thus their data are considered in the data analysis comparing ATPA and T-TSAFE under IFR operating condition only.

A. Total Number of Alerts Generated & Displayed

The total number of alerts generated by the T-TSAFE algorithm versus the alerts that were displayed is shown in Fig. 6 for IFR and the Mixed operating conditions. The total number of alerts generated by T-TSAFE is based on a look-ahead time set inside the T-TSAFE algorithm whereas the alerts displayed in the data tag to the controller are managed by several factors, some of which are controlled of the controller, such as aircraft under visual approach, controller look-ahead time, and presence of cones. The alerts displayed to the controller impacts the controller’s workload therefore it

is compared with the Total number of alerts generated. As depicted in Fig. 6, T-TSAFE generated significantly larger number of alerts under the Mixed condition (average of 17) than IFR condition (average of 10) ($F(1,126)=15.97$, $p<0.001$). The higher number of alerts generated for the Mixed operating condition is due to the fact that aircraft under visual separation come very close to other aircraft because they have no standard separation requirement. It is interesting to note that the total number of T-TSAFE alerts displayed is considerably smaller than the number of alerts generated. On average 8 alerts were displayed during the course of a 40 minute run on each controller station. The reason for the low number of alerts being displayed is because alerts are suppressed when aircraft are on visual approach, have ATPA cone or are outside a controller's look-ahead time (discussed in the next subsection). All these factors contribute to the low number of alerts displayed on the aircraft.

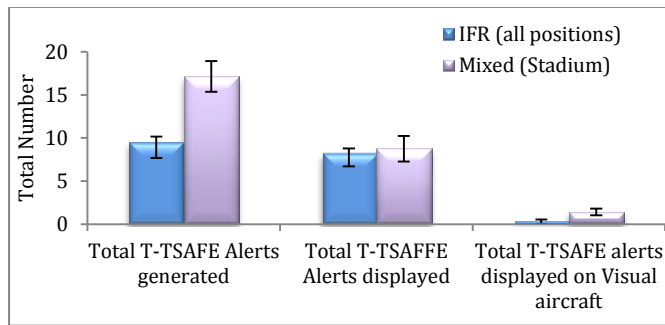


Figure 6. Total Number of alerts generated vs. displayed (IFR vs. Mixed)

An ANOVA revealed a significant difference in total number of alerts displayed for the visual aircraft (one on an average) versus none for IFR ($F(1,126)=17.38$, $p<0.001$). In general, most alerts on aircraft under visual separation were suppressed, except any alerts with general aviation aircraft flying under visual flight rules (VFR aircraft).

Fig. 7 shows the Total Number of alerts generated versus displayed for T-TSAFE cones vs. ATPA cones condition for the two final controllers -Stadium & Downe. Both the ATPA and the T-TSAFE cone conditions are provided with different cones in the final approach, but T-TSAFE alerts show in the data tags for rest of the traffic in the airspace. It was found that the cone condition did not impact the number of alerts generated by the T-TSAFE algorithm and no significant differences were yielded on ANOVA. As mentioned earlier, the number of T-TSAFE alerts generated for ATPA and T-TSAFE cone condition has the same T-TSAFE algorithm working in background and thus the number is quite similar (about 15 alerts per run). Fig. 7 also shows that the number of alerts displayed in the two conditions is somewhat similar. About 12 T-TSAFE alerts were shown in the ATPA condition and 15 alerts were shown in the data block of aircraft in T-TSAFE cones condition reaching marginal significance on ANOVA ($F(1,44)=3.4$, $p<0.07$). The reason for this difference lies in the fact that T-TSAFE alerts for compression errors are suppressed when ATPA cones are depicted on the aircraft,

whereas the alerts are partially shown on the aircraft with T-TSAFE cones, providing the controller with time to predicted LoS in the data tag. There was a significant difference in the alerts shown on visual aircraft in the ATPA condition as compared to T-TSAFE condition ($F(1,44)=4.86$, $p<0.05$). It is possible that the confederates managed to create more alerts with aircraft under visual condition (about 1 more alert) in ATPA than in T-TSAFE condition. The only alerts that were depicted on the aircraft under visual separation were alerts with VFR aircraft.

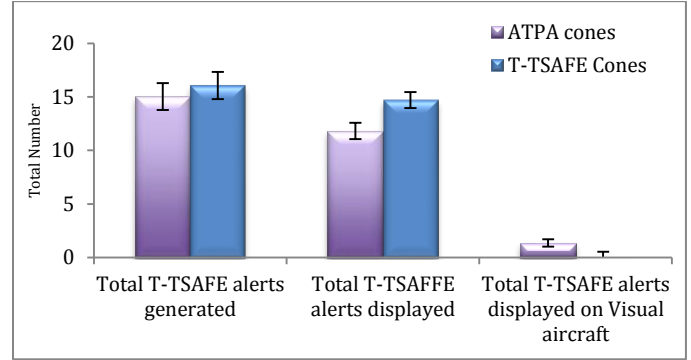


Figure 7. Total Number of alerts generated vs. displayed (ATPA vs. T-TSAFE cone conditions)

B. Controller Look-ahead Time

The controller manipulated look-ahead time was a new concept in the study. The look-ahead time inside the T-TSAFE algorithm was set at 120 sec. The controller was allowed to manipulate the "controller look-ahead," as it impacted the display which allowed the controller to decide how far in advance they wanted to display the alerts. Controller participants could, for example, choose 45 sec as the look-ahead, for which they would see alerts with time to predicted LoS below 45 sec. However, the participants often confused this to mean that they would get every alert at 45 sec to conflict. This means they will have to be trained well to accurately use the controller look-ahead time.

The different analyses show that controllers prefer 60 sec as the look-ahead time for getting alerts in their respective scopes. Any alerts generated by T-TSAFE with time to predicted LoS greater than the controller look-ahead time were suppressed by the system and not displayed to the controller. There were no significant differences found on a chi square test, where the expected frequency of a certain look-ahead time was compared with the actual frequency of that look-ahead time between IFR and the Mixed conditions. There was a similar tendency for the controllers to select 60 sec most frequently irrespective of the type of cone – ATPA or T-TSAFE (Fig. 8). The look-ahead time can interact with the Time-to-Predicted-LoS provided by the algorithm. Similar to the T-TSAFE alerts, T-TSAFE cones were also impacted by controller's look-ahead time as controllers did not see any warnings for compression errors on T-TSAFE cones unless the time-to predicted-LoS was below the controller's look-ahead time. In the case of ATPA cones, since the warning alerts on the cones are based on hard-coded numbers i.e. time-to-

predicted-LoS being 45 sec invoked a yellow cone, and it being 24 sec or less invoked an orange cone, controllers' look-ahead time had no impact on the ATPA warning cones. Since controller look-ahead time does not impact the display of alerts on ATPA cones, this presents integration and training issues when ATPA cones and T-TSAFE alerts are integrated.

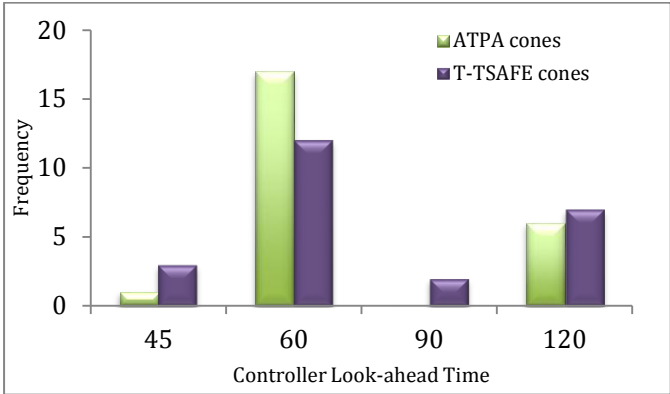


Figure 8. Frequency of different Controller Look-ahead times ATPA cones vs. T-TSAFE cones (Downe & Stadium Controller)

C. Duration of Displayed Alerts

The duration of the alerts displayed for the IFR conditions is compared with the Mixed Condition in Fig. 9. The duration of the alerts is longer in the IFR conditions (61 sec compared to 44 sec in the Mixed) because in the Mixed condition, only the alerts with VFR aircraft are shown. There is no standard separation required with VFR aircraft, but the algorithm uses a 1.5 nmi lateral and 500 ft vertical separation to generate alerts between IFR and VFR aircraft. The alert durations did yield significant differences between the IFR and the Mixed conditions ($F(1,1201)=4.98, p<0.05$).

The Duration for the alerts displayed under the ATPA and T-TSAFE condition is shown in Fig. 10. The T-TSAFE alerts with ATPA are suppressed as soon as the cones appear, which explains the lower duration of the T-TSAFE alerts on the ATPA cones condition. There was marginal significance between the duration of T-TSAFE alerts shown in the ATPA cones and T-TSAFE cones conditions ($F(1,650)=3.27, p<0.07$). The duration of the T-TSAFE alerts on the ATPA cones is still 60 sec giving the controller enough time to deal with them.

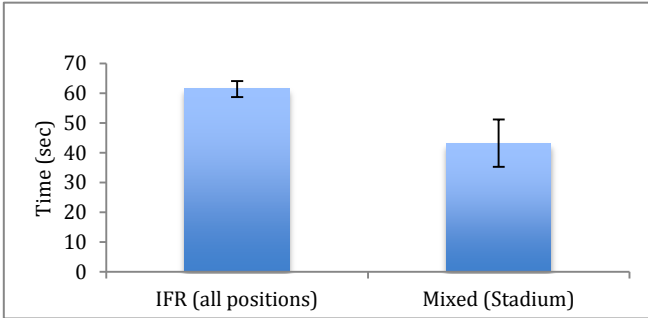


Figure 9. Duration of Alerts IFR (All positions) vs. Mixed (Stadium only)

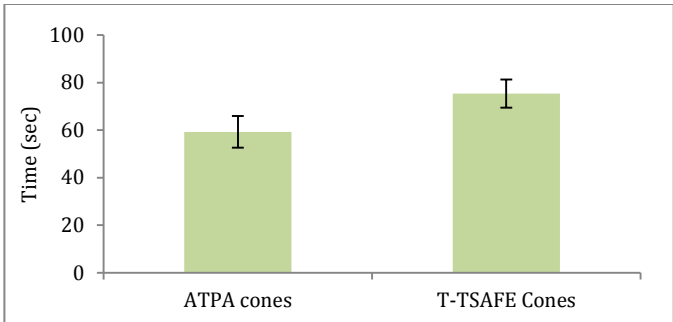


Figure10. Duration of Alerts ATPA vs. T-TSAFE

D. Keyboard Entries

Controllers made altitude inputs, which are similar to cleared flight levels or assigned altitudes, into the system. The number of these altitude entries is compared across the conditions. It was found that controllers make about two altitude entries per run per controller station and there was no difference between the IFR and Mixed conditions (Fig. 11). The number of altitude entries may be small because the T-TSAFE algorithm derives flight intent information from the published nominal approaches that aircraft are expected to fly. The altitude entries made by the controller in one station are shared with the other controller station, providing shared situational awareness. Similarly, no difference between the altitude entries was observed between the ATPA and T-TSAFE cones condition (Fig. 12).

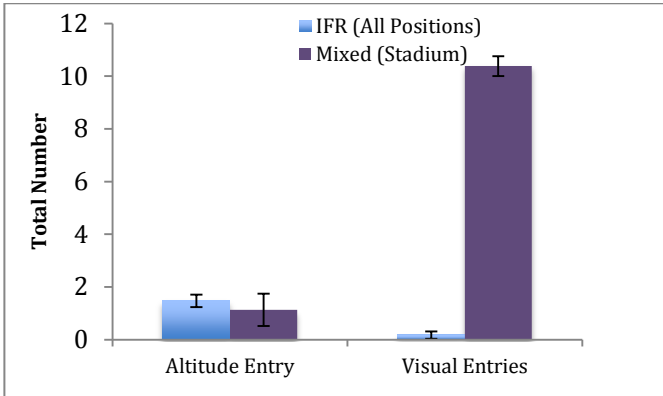


Figure 11. Altitude and Visual entries for IFR (all positions) vs. Mixed (Stadium)

The visual operations under different conditions are also analyzed for visual entries. These are the “4R” entries made via keyboard on aircraft on visual approach (Fig. 5). There is a significant difference in the entries made for visual approach under the Mixed condition as compared to IFR condition (Fig. 11) as indicated by the ANOVA ($F(1,126) = 630.2, p<0.001$). This result is expected since visual approach entries were allowed only under the Mixed condition. The difference in the cones did not impact the visual approach entries (Fig. 12).

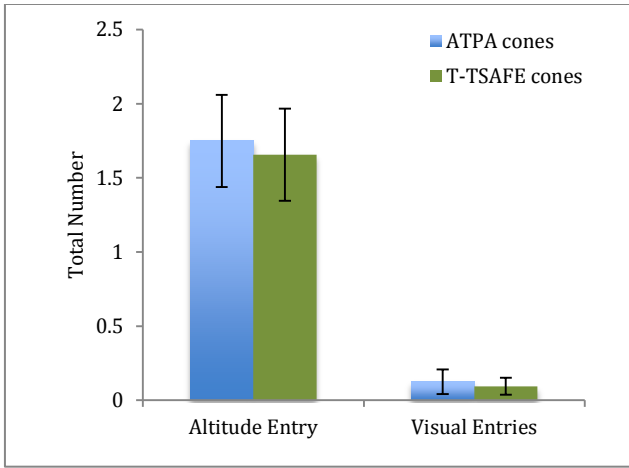


Figure 12. Altitude and Visual entries for ATPA cones vs. T-TSAFE cones (Downe & Stadium)

E. Workload & Situational Awareness

Participants completed the NASA TLX workload questionnaire [12] after every run. Data were collected on each of the six TLX workload measures. In addition, a seventh variable measuring overall workload combining all six of these measures was derived. The overall workload variable, also known as the “composite” measure, once derived, was then scaled down to match the 1-to-5 range for direct comparison with the other six measures (1=very low, 5=very high). Also, the “performance” measure was analyzed on an inverse scale, so a higher score indicates lower performance. Participants also completed an abbreviated version of the Situational Awareness Rating Technique (SART) scale at the end of each simulation run [13]. The participants responded to questions on the demands the situation posed on them and their understanding of the situation offered to the user by the displays and procedures. They also responded to a question on attention capacity that refers to the user’s skills and attention needs. The situational awareness scales ranged from 1 to 7, i.e., from very low to very high situational awareness.

The results on workload (Fig. 13) and Situational Awareness (SA) (Fig. 14) show that there were no significant differences yielded on the ANOVA when IFR conditions were compared with the Mixed. There were subtle trends observed, controllers reported somewhat decreased workload under mixed operating conditions. Visual operations usually decrease workload on the controller because the responsibility for separation is delegated to the flight deck. It is interesting to note in Fig. 6 that visual aircraft did not get many alerts displayed, as they do with the legacy system CA, which can potentially increase workload. In fact they received less than 1 alert per run, which was caused by general aviation aircraft under visual flight rules. All other alerts on visual aircraft were suppressed. Similar trends are seen with Situational Awareness (SA) data; trends show that the demand on attention is lower for the Mixed condition. There were no differences on the rest of SA variables.

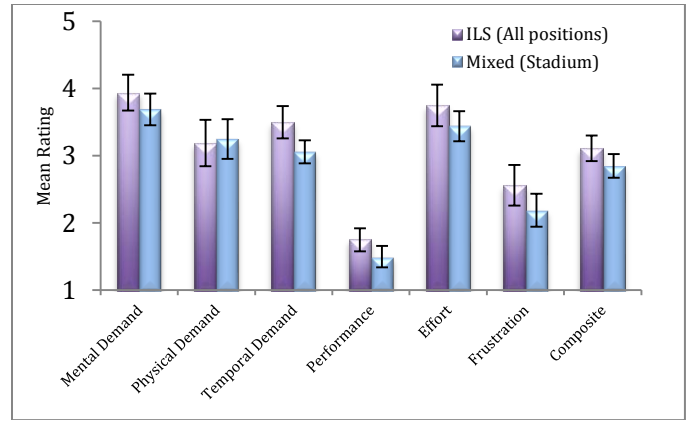


Figure 13. Workload IFR (all positions) vs. Mixed (Stadium only)

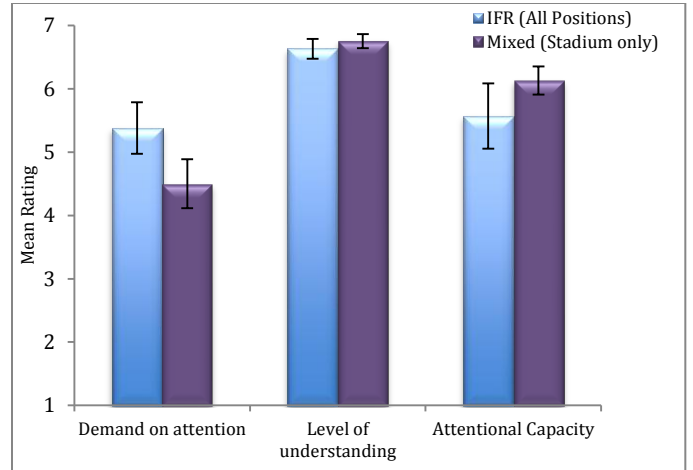


Figure 14. Situational Awareness - IFR (all positions) vs. Mixed (Stadium only)

The workload reported by the controller participants was compared for the T-TSAFE cones and ATPA cones under the IFR operating conditions. These were considered because the only controller positions that used the cones were the final approach controllers. The Mixed operating conditions were not included in the analysis because between the two Final Approach controllers, only the Stadium controller was allowed to have visual separation between some aircraft. Analysis of Variance (ANOVA) did not yield any statistical difference between the ATPA and T-TSAFE under IFR operating conditions on the workload and SA measures. It is worth noting that despite the differences between the ATPA and T-TSAFE cones, the controllers did not perceive them differently in terms of workload or SA. ATPA is currently fielded in some of the US TRACONS. The similarities in the workload and SA reported for the ATPA cones and T-TSAFE cones conditions will make bringing T-TSAFE cones in the air traffic controllers’ work environment easier in future. The controllers were not confused about whether they were working with T-TSAFE cones or ATPA because they reported that the T-TSAFE cones appeared on aircraft much sooner than the ATPA cones. Thus there is anecdotal evidence that T-TSAFE cones did provide the controllers better situational

awareness than the ATPA, but no subjective measures to support it.

F. Safety & Controlability

The controller participants were asked to rate operations for safety, controllability and acceptability on a scale of 1 to 5, where 1 referred to the lower end of the scale and 5, referred to the higher end of the scale. The controller participants on an average reported high levels on safety, controllability and acceptability of the operations. On the questions asked about the safety, controllability and acceptability of IFR operations as compared to the Mixed operations, no difference in the ratings were reported by the controller participants. Similarly, no significant differences were reported between the operations for ATPA cones vs. T-TSAFE cones for the Stadium & Downe controllers.

G. Comparison of Features between ATPA cones & T-TSAFE cones

Controllers were also asked rate their preference over the features of ATPA and T-TSAFE cones (Fig. 15). These features have been described in Table I. Forty percent of the controllers preferred the ATPA cones warning for showing compression error, whereas sixty percent of the controllers prefer that the T-TSAFE cones show LoS, which means that altitude separation between aircraft do not result in warning cones under T-TSAFE cones, even if lateral separation is less than the minimal requirement. The controller's preference for T-TSAFE and ATPA on LoS vs. compression error was similar, resulting in a non-significant binomial test.

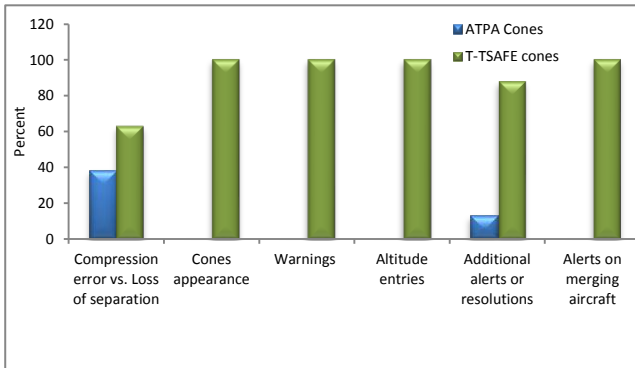


Figure 15. Controller preference for features of T-TSAFE cones and ATPA

Among all the other features, The T-TSAFE cone features such as their warnings, their early appearance, the impact altitude entries have on the cones, and alerts shown for merging aircraft were preferred by almost 100% of the participants over the ATPA features. All other features yielded significantly favorable results for T-TSAFE cones with significance achieved at 99% probability level. Only 10% of the controllers did not want the additional alerts provided by the T-TSAFE, whereas 90% of the participants preferred the additional alert information such as the time-to-predicted LoS shown on the T-TSAFE cones that was missing in the ATPA

cones. This result on additional alert information achieved marginal significance with $p < 0.07$ on a binomial test.

H. Complacency in Automation

A Complacency Potential Rating Scale was used to collect data on automation-induced complacency [14]. Wiener [15] defined complacency as “a psychological state characterized by a low index of suspicion.” Automation is often identified as a significant factor that induces complacency. Procedures, roles and responsibilities are also potential factors that induce complacency. According to Wickens [16], reliability in automation engenders excessive trust and over-reliance in pilots. Singh et. al. [14] identified four factors that may be related to over-trust or complacency in automation. These are confidence, reliance, trust, and safety in automation. Some examples of scale items that measure different complacency constructs are shown in Table III.

TABLE II. EXAMPLES OF STATEMENTS USED TO MEASURE COMPLACENCY IN AUTOMATION

Confidence	T-TSAFE makes air traffic in the terminal environment safer under IFR conditions.
Reliance	T-TSAFE cones have made the controller's job easier.
Trust	T-TSAFE is more likely to be correct than manual conflict detection under visual conditions.
Safety	I feel safer having ATPA driven cones than relying on manual conflict detection.

The Complacency Potential Rating Scale was adapted and used to collect data for all controller positions across all conditions. The scale uses a 5-point Likert scale that ranges from ‘strongly disagree’ to ‘strongly agree.’ Some of the questions in the rating scale were reversed to ensure reliability in the responses. The scale was adapted to ask questions about the IFR, Mixed, ATPA cones, and T-TSAFE cones.

Fig. 16 shows the controller complacency ratings, comparing IFR operating conditions to The Mixed operating conditions and comparing the T-TSAFE cones with ATPA cones. Statistically significant ANOVA differences were found for several constructs of complacency and they have been outlined in Table IV.

The results show that there are significant differences in the level of confidence, reliance, trust and safety for operations type. IFR operations have consistently higher levels of confidence, reliance, safety and trust than the Mixed operations. Similarly, there are significant differences in the level of confidence and trust for the T-TSAFE cones showing that participants were beginning to rely on the T-TSAFE cones much more than the ATPA cones. Previous research has examined automation complacency [17] [18] and the extent to which over-reliance on automation can lead to operational errors (e.g., in the case of occasional automation failures). This might suggest that very high or very low levels of automation complacency are not desirable, but rather, optimum levels of automation complacency would be somewhere between these two extremes. Thus neither mistrust nor over-reliance in the automation is desirable. The high scores on T-TSAFE indicate over reliance on the tool and warrants extra caution during deployment.

TABLE III. SIGNIFICANT RESULTS ON VARIOUS CONSTRUCTS OF POTENTIAL FOR COMPLACENCY

Construct	F statistic (df values)	Significance
Confidence	$F(1,7) = 15.91$	Significant for operation type at $p < 0.005$
Confidence	$F(1,7) = 4.82$	Marginally Significant for cone type at $p < 0.06$
Reliance	$F(1,7) = 5.90$	Significant for operation type at $p < 0.05$
Trust	$F(1,7) = 14.97$	Significant for operation type at $p < 0.05$
Trust	$F(1,7) = 3.94$	Marginally Significant for cone type at $p < 0.08$
Safety	$F(1,7) = 6.67$	Significant for operation type at $p < 0.05$

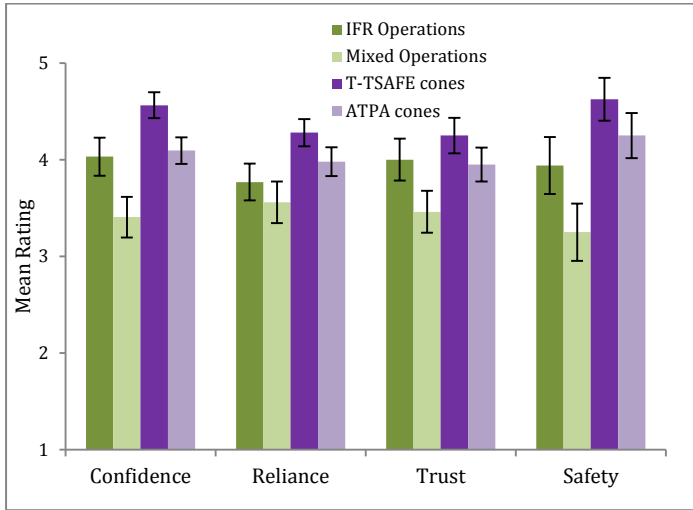


Figure 16. Potential for complacency compared across conditions.

I. Usability Functions

The controller participants also rated on a scale of 1 to 5 their subjective responses towards several questions related to procedures, information requirements, and usability. Significant results were found on the ease of locating aircraft with potential LoS, awareness to potential LoS and timeliness of alerts.

The controllers reported that it was easier to locate an aircraft with potential LoS with T-TSAFE cones (Fig. 17) as compared to ATPA cones ($F(1,7)=5.727$, $p < 0.05$). This result makes sense because the T-TSAFE cones appear sooner than the ATPA cones. The controllers also had an easier time maintaining awareness of potential loss of separation than the ATPA cones ($F(1,7)=7.0$, $p < 0.05$). This may be due to the fact that the T-TSAFE cones have warnings that have additional information such as time to predicted LoS shown in the data, block. The consistency between the alerts and the warning cones also makes for better alerts with T-TSAFE cones than ATPA cones. It was also found that T-TSAFE cones performed significantly better than the ATPA cones on timeliness of alerts ($F(1,7)=7$, $p < 0.05$). Again the features of T-TSAFE such as cones appearing on the aircraft 30 sec before the aircraft is established on localizer, and providing warning for aircraft that are ahead of the schedule of the current aircraft whereas ATPA

provides warnings with aircraft that are physically ahead of it, and not necessarily ahead in the schedule. Overall, T-TSAFE cones performed similar to or better than the ATPA cones.

There were no significant differences in the ease of locating potential LoS between IFR and Mixed operations. Similarly, there are no significant differences between IFR and the Mixed operating conditions for the responses towards maintaining awareness of LoS or on the timeliness of alerts. Thus, the operating condition did not impact the nature of alerts or any functions related to conflict detection.

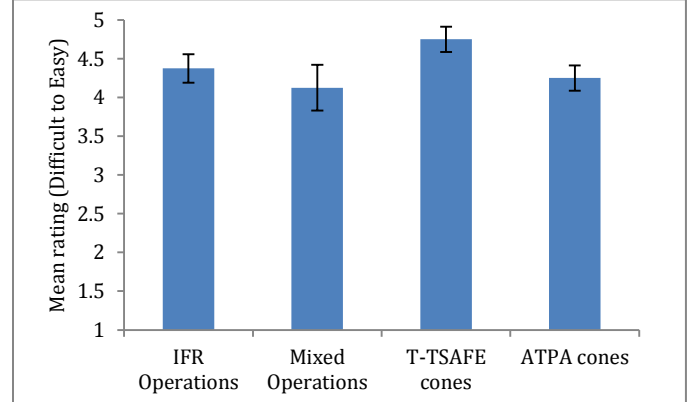


Figure 17. Subjective responses on ease of locating aircraft with potential loss of separation

VI. CONCLUSIONS

The study investigated a tactical conflict detection tool (T-TSAFE) in the terminal area. This tool combines dead reckoning with flight intent where possible and has fulfilled many of the requirements set by Eurocontrol's guidelines for a STCA. Initial and follow-up human-in-the-loop air traffic control simulation experiments were conducted, to test the human factors of this new conflict detection and resolution tool, T-TSAFE. Whereas the initial investigation verified T-TSAFE as an improvement over the legacy conflict detection system currently used in the field, it also revealed aspects of the T-TSAFE system that require further investigation [5]. To address this need, a follow-up experiment was conducted, testing T-TSAFE under four experiment conditions. The first two conditions varied the operating conditions- IFR vs. the Mixed conditions where aircraft were allowed to have visual separation in the latter. The second and third conditions varied the software driving the cones - Automatic Terminal Proximity Alert (ATPA) and T-TSAFE. The cones are a graphical tool used for monitoring final approach and providing a warning for possible compression errors in the final approach phase of flight. The test bed for the investigation was simulated-Southern California TRACON.

Workload and Situational differences were not found for either cone type or operating type. But trends showed that the Mixed operating condition was easier on the controller with respect to attentional capacity and workload, because for visual operations the controllers delegate responsibility for separation to the flight deck. The controller participants preferred to see alerts within 60 sec of conflict, even though they had the choice of 45 sec, 90 sec and 120 sec as controller look-ahead time. They were provided with two levels of alerts - red and yellow

and used the color of the alert to prioritize their cognitive resources.

Controller participants reported preferring most of the T-TSAFE cones' features to the ATPA cones' features. They particularly liked the fact that T-TSAFE cones appeared 30 sec before getting established on the localizer making it easy to locate an aircraft having potential LoS and to maintain awareness of the LoS. They found the alerts provided by T-TSAFE as very timely. There was also higher consistency between the alerts and cones in case of T-TSAFE cones, when compared to ATPA cones.

For the subjective responses on complacency towards automation, T-TSAFE cones were being relied upon more than ATPA cones. The Mixed operating procedures are keeping the controllers in the optimum zone for complacency for automation.

The comparison between IFR and Mixed operations for T-TSAFE has shown that Mixed operations do not increase the workload or decrease situational awareness, suggesting that the tool is not adding any unnecessary alerts in the Mixed condition. Thus, this investigation suggests that having one system (T-TSAFE) that shows the alerts in the data blocks and also drives the cones in the final approach will circumvent the need for integrating different systems. Previous results have shown T-TSAFE an improvement over the legacy system. The results of this study show similarities between the ATPA cones and T-TSAFE cones will make it easier to migrate the air traffic control system from ATPA cones to T-TSAFE cones. The study also shows that T-TSAFE alerts and ATPA cones do to increase undue workload or confusion, thus the transition of T-TSAFE alerts with ATPA in the final approach holds much potential.

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